

# NASA Phase I Project Summary

Nonproprietary

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**Firm:** Creare Incorporated

**Contract Number:** NNX13CG22P

**Project Title:** Lightweight Superconducting Magnets for Low Temperature Magnetic Coolers

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## Identification and Significance of Innovation:

We propose to develop an Active Magnetic Regenerative Refrigeration (AMRR) system that can provide continuous remote cooling at temperatures in the range of 2 K and reject heat at temperatures higher than 15 K. The magnetic cooler directly addresses the cryogenic technologies requested by Topic S1.06 for Highly Efficient Magnetic and Dilution Cooling Technologies. The AMRR system uses Creare's vibration-free, reversible cryogenic circulator to propel a low-pressure  $^3\text{He}$  flow through micromachined magnetic regenerators, and thus allows a lightweight AMRR to achieve a large cooling power at high efficiency. Furthermore, the alternating continuous flow in the AMRR will enable remote distributed cooling, allowing a detector(s) to be located far away from the cooler.

The proposed AMRR system uses three key technologies: (1) a vibration-free cryogenic reversible circulator, (2) micromachined magnetic regenerators, and (3) superconducting magnets. The technology for the reversible cryogenic circulator was demonstrated under a prior NASA project. The highly effective magnetic regenerator is being developed under an ongoing NASA program. The innovation proposed here is an advanced low-current, lightweight superconducting magnet that produces a 3 to 5 tesla (T) gradient magnetic field with an optimum time-varying spatial distribution to enable the AMRR system to achieve high thermal efficiency.

## Technical Objectives and Work Plan:

The overall technical objective is to develop a lightweight, efficient AMRR system that will provide efficient cooling for low-temperature space detectors. We first identified optimum superconductor wires for the AMRR magnets, optimized the magnet winding design to achieve a field profile that will enable efficient system operation, and developed a fabrication plan for the magnet. We then developed the thermal and mechanical designs for integrating the magnets with an AMRR system. Finally, we optimized the current waveform to enable the AMRR system to achieve a high thermal efficiency.

## Technical Accomplishments:

In Phase I we evaluated candidate superconducting materials and identified most promising materials for the AMRR magnets. Based on the characteristics of these magnet materials, we performed trade-off studies to identify the optimum magnet designs that achieve proper balance among thermal efficiency, system size and mass, and technical risk. We optimized the winding design, determined the magnetic field distribution, and estimated the magnet parasitic losses. We developed a preliminary design of a highly efficient power supply for the SC magnet. We developed a mechanical structural support for the magnet and the regenerator. We optimized the current waveform of the SC magnet to maximize the regenerator efficiency. We estimated the thermal performance of the regenerator driven by the candidate magnets and the overall AMRR system performance. Our analyses show that the overall system can achieve a COP of 3.4% of the Carnot COP when the warm end of the regenerator operates at 11 K, and a COP of 2.8% when the warm end operates at 15 K. All technical objectives were successfully completed and the results show the feasibility of the proposed concept.

**NASA Application(s):**

The proposed AMRR system will enable NASA to carry out future space astronomy missions that use cryogenic infrared, gamma ray, and X-ray detectors. These detectors need to operate at temperatures in the range of 4 K to below 1 K to reduce the thermal emission of the detectors themselves and to achieve high sensitivity and resolution. The vibration-free, lightweight AMRR can provide efficient cooling for these missions at the required temperature ranges. The fabrication technologies developed for the lightweight superconducting magnets can also be applied to the fabrication of advanced magnets for multistage active demagnetization refrigerators (ADRs), particle accelerators, and portable MRIs.

**Non-NASA Commercial Application(s):**

Military applications for the proposed magnetic cooler include cooling systems on space-based surveillance, missile detection, and missile tracking systems. Scientific applications include cooling systems for material microanalysis using X-ray microcalorimeter spectrometers, superconducting radio frequency cavities, superconducting cavities, and superconducting digital electronics.

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